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**Delay Discounting and Smoking:
Robust correlation, but uncertain causation**

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In their systematic review, Barlow and colleagues (1) report robust evidence that steep delay discounting, the tendency to prefer smaller short-term rewards over larger long-term rewards, is a risk factor for smoking and, more tentatively, unsuccessful cessation. This extends previous work (2, 3), in particular by incorporating evidence across the life course that captures different stages of smoking behaviour, from initiation through to cessation. Smokers discount the future more than non-smokers, and this predicts future smoking, and in particular decreased likelihood of successful smoking cessation. Critically, the authors highlight the lack of high quality prospective data, despite dramatic growth in the number of studies on time-discounting and smoking published in recent years. It is likely that these associations are not unique to cigarette smoking, and extend to other health behaviours, including use of other substances (2, 3), obesity (3), and attention deficit hyperactivity disorder (3). For all of these conditions, three important questions remain unanswered.

First, what are the temporal and, more importantly, causal relationships between delay discounting and health behaviours? This remains unclear, in part, because of the dearth of high quality prospective studies. This is particularly the case in terms of discounting as a causal etiological variable. In the review by Barlow and colleagues, only 4% of the studies were identified as prospectively evaluating discounting as a predictor of smoking initiation and progression. Furthermore, on closer inspection, one of those studies only reported cross-sectional findings (4). Steep delay discounting may be a risk factor for smoking, but neurobiological changes resulting from smoking may increase time-discounting, or confounding factors such as socioeconomic position may influence both. This first question could readily be addressed by the incorporation of standard time-discounting measures in cohort studies. In our opinion, standard self-report measures of monetary discounting would be adequate, given the evidence reported by Barlow and colleagues that results did not differ substantially depending on whether monetary or cigarette rewards were

used. This would provide a general measure of time-discounting and there is a clearly a need for more longitudinal cohort studies to disentangle causation from correlation.

Second, how does steep delay discounting fit into the larger etiological understanding of smoking and related conditions? This second question is more difficult to answer for obvious reasons – even high-quality prospective data are imperfect to definitively answer questions of causality. It is likely that steep discounting is influenced by genetic variation (4), and it may represent a mechanism through which a proportion of genetic risk of smoking operates (5). While specific genetic variants associated with steep discounting have yet to be consistently identified, if a sufficient number of cohort studies collect standardised (or at least comparable) measures, and those also hold DNA on participants, genome-wide association studies may reveal genetic variants associated with individual differences in delay discounting. This in turn would support Mendelian randomisation studies investigating the causal impact of time-discounting and a range of outcomes (i.e., treating steep discounting as an exposure and using genetic variants associated with steep discounting as an unconfounded proxy of this exposure). In principle, this will allow the causal impact of steep discounting on smoking, and the impact of smoking on discounting, to be explored. Environmental exposures such as early life adversity or stress are also associated with steep discounting of future rewards (6, 7), and genetically-informed longitudinal studies will be essential for elucidating the relative contribution of these influences. In particular, genetically-informed longitudinal investigations will be essential to distinguish between genuine causal pathways and alternative pathways (e.g., risk of attention deficit hyperactivity disorder, biological pleiotropy, etc.) that may independently influence both time-discounting and smoking.

Third, if high time-discounting is indeed a causal risk factor for subsequent risk behaviours, is it modifiable? There is growing interest in cognitive modification techniques, which target a range of cognitive processes, from emotion recognition to working memory (8). Interventions to promote lower delay discounting, particularly if delivered in critical developmental periods such as adolescence, may reduce risk behaviours in early

adulthood. Indeed, working memory training has been shown to decrease delay discounting among individuals with stimulant addiction (9).

Achieving this goal of understanding the causal nature of the associations between delay discounting and health behaviours such as smoking, and then developing interventions to target this mechanism, if it is indeed found to be a causal risk factor, will require the collaboration of many disciplines, including epidemiology, genetic epidemiology, experimental psychology and biological psychiatry. In particular, the foundational work – high-quality prospective, genomewide association and Mendelian randomisation studies – depends critically on the incorporation of measures of time-discounting by epidemiologists and genetic epidemiologists. It is therefore sobering that Barlow and colleagues find that the main disciplines that emerge from an analysis of journal co-citation patterns are psychology, pharmacology, economics, and neuroscience. The authors report a “dearth of studies in epidemiology and public health,” despite the potential importance of such a wide-reaching risk factor. In an era when multidisciplinary and “team science” is increasingly emphasised, the review by Barlow and colleagues highlights that we may need to redouble our efforts to reach across disciplinary boundaries and incorporate concepts and constructs that may be novel to some but have a robust empirical foundation.

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